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September 26, 1997

EX PARTE OR LATE FILED

John Cimko, Chief
Wireless Telecommunications Bureau
Policy Division
Federal Communications Commission
2025 M Street, N.W.
Washington, D.C. 20554

Re: Follow Up on Motorola *Ex Parte* Presentation on September 15, 1997
Regarding Enhanced 911 Services; CC Docket No. 94-102

Dear John:

On behalf of Motorola, Inc. ("Motorola"), I wanted to thank you, Ron Netro, Dan Grosh and Won Kim for taking the time to meet with Mary Brooner, Mark Birchler, and I on September 15, 1997, to discuss E911 automatic location technology. As we discussed at the meeting, I have enclosed non-proprietary copies of the presentation Mark used at the meeting.

Please do not hesitate to call me at (202) 828-3182 if any questions arise concerning this material.

Sincerely,

Eric W. DeSilva

Enclosures: Presentation
cc: Ronald Netro
Daniel Grosh
Won Kim
William Caton (for CC Docket No. 94-102 *Ex Parte* File)

Motorola LMPS Research

TERRESTRIAL RF LOCATION SYSTEM ACCURACY

Mark A. Birchler

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15 September 1997

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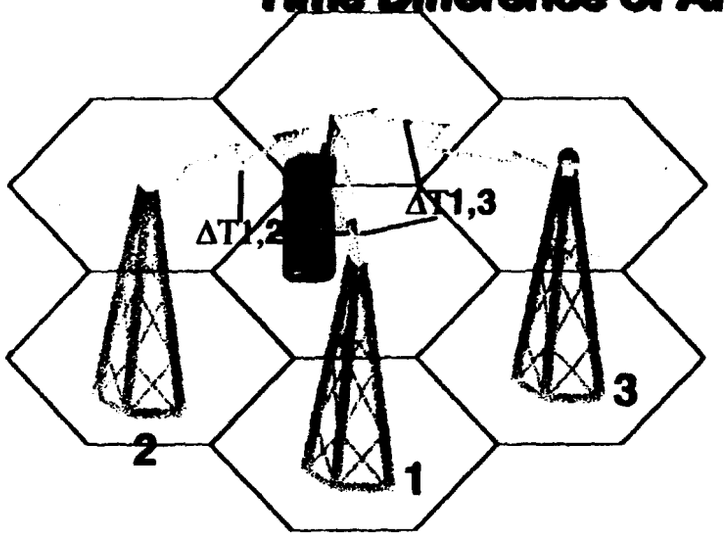
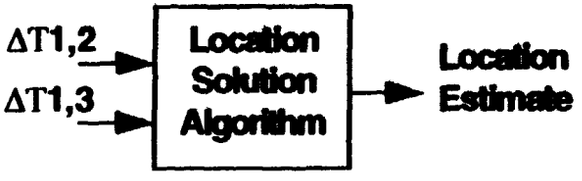
TDOA Location Finding Fundamentals

Time Difference of Arrival (TDOA)





- Measurements to at Least 3 Sites Required for a Complete Solution
- Minimizes Deployment Costs
  - Allows Reuse of Site/Subscriber Antenna Systems
- Technology of Choice for Other Key Players (e.g., Associated Group)

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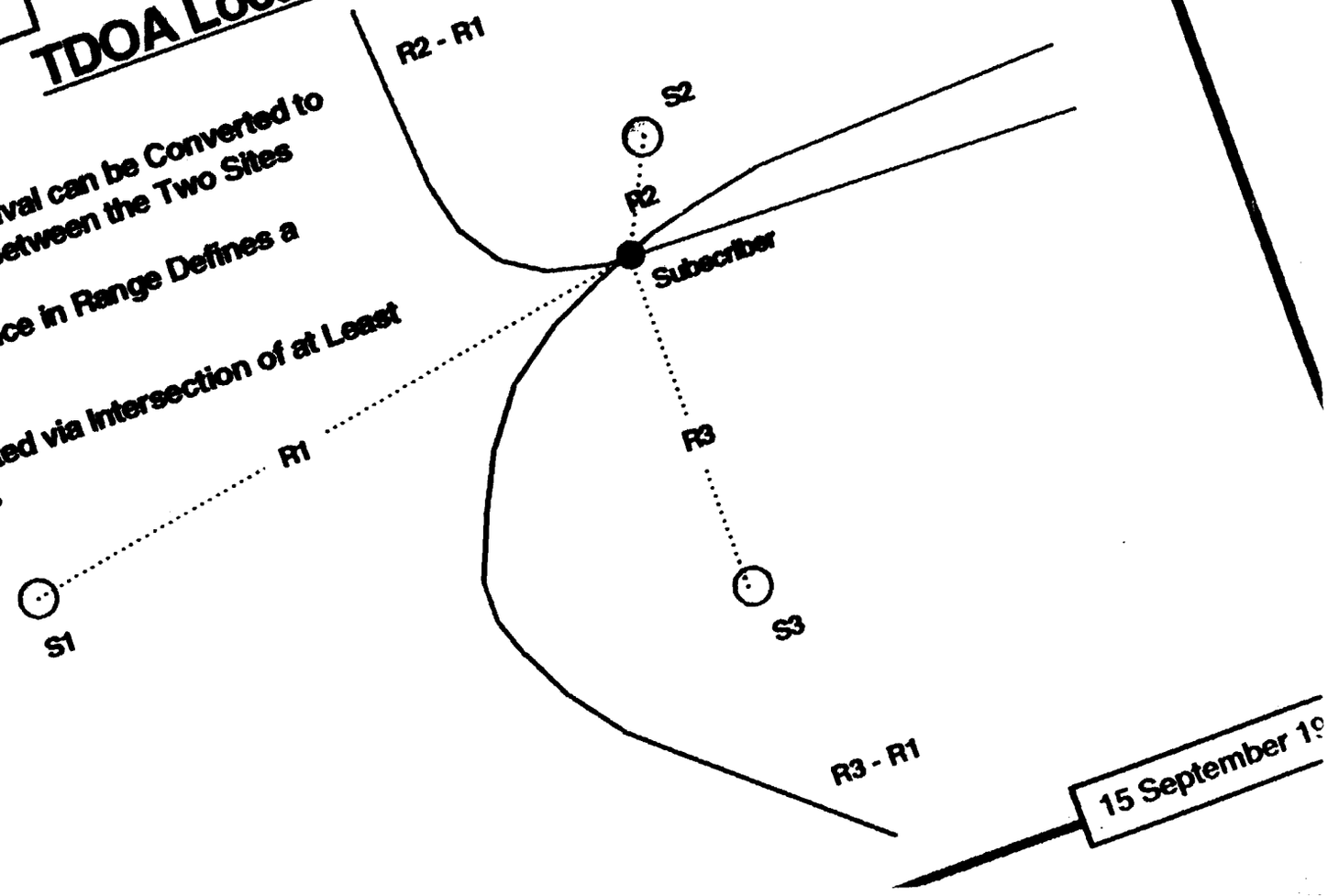
TDOA Location Solution

- Time Difference of Arrival can be Converted to Difference in Range Between the Two Sites
- A Constant Difference in Range Defines a Hyperbola
- Location Estimated via Intersection of at Least Two Hyperbolas

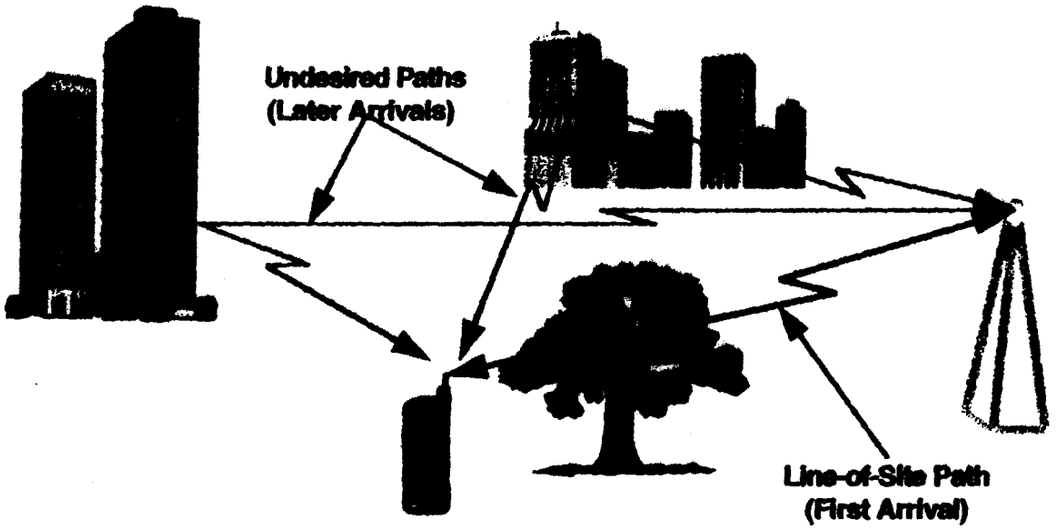


Sources of Error: Environmental

TDOA Based Location System Assumed

- **Noise**
  - **Undesired Process Added to Desired Signal in the Receiver Front End**
  - **Accuracy Degradation Inversely Proportional to Measurement Average Time**
- **Fading**
  - **Variation of the Received Signal Power due to Scattering Environment**
  - **Accuracy Degradation Inversely Proportional to Measurement Average Time**
- **Distortion**
  - **Desired Signal Altered due to Hardware/Software Imperfections**
  - May Induce Measurement Bias which Is Not Reducible by Averaging
- **Co-Channel Interference**
  - **Reception of Undesired Signals Operating on the Same Carrier Frequency**
  - May Induce Measurement Bias if Interfering Signal is Similar to the Desired
- **Multi-Path Propagation**
  - **Reception of Multiple Copies of the Desired Signal due to Reflection Off of Buildings, Mountains, etc.**
  - **Induces Measurement Bias which Is Not Reducible by Averaging**

Multipath Propagation: First Arrival = Line-of-Sight Path



- Optimum Location Solution Requires Isolation of "First Arrival" Signal
- Ability to Detect "First Arrival" Dependent on Signal Bandwidth & S/N
- Unresolvable Signal Components Bias Measurement
  - Results in an Irreducible Limit on Accuracy
  - Limit Depends on Signal Bandwidth and S/N

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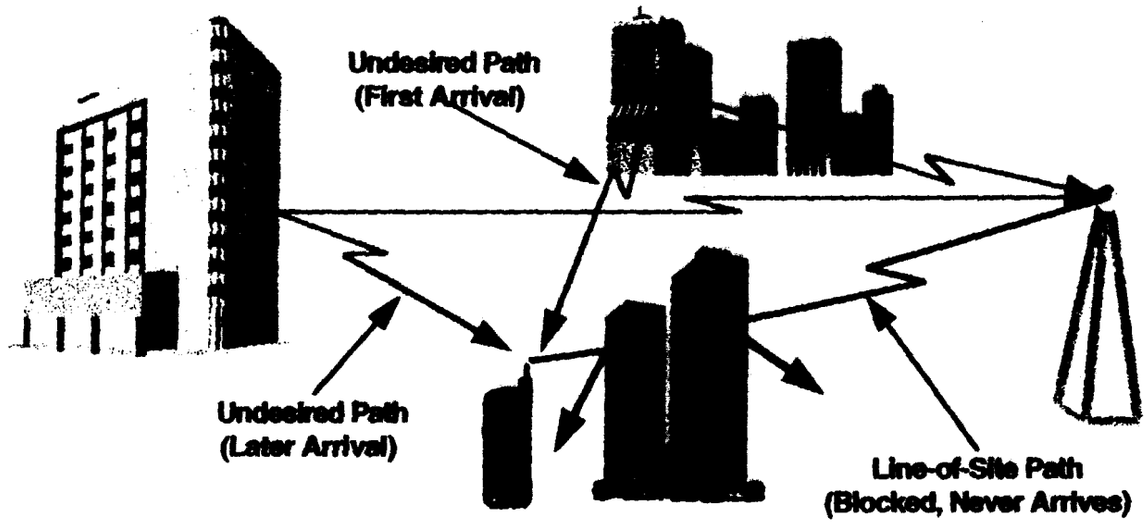
Multipath Propagation: First Arrival ≠ Line-of-Sight Path



- The "First Arrival" May Not Have Traversed the "Line-of-Sight" Path
  - Most Location Finding Techniques Assume Access to the Line-of-Sight Path
- Causes an Irreducible Lower Limit on Location Accuracy for Most Systems

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Sources of Error: System

- **Geometry**
  - **Arrangement of Sites/Subscriber in Space Affects Accuracy**
  - Geometrical Effect Acts as a "Magnification Factor" on Measurement Errors
    - **Referred to as Horizontal Dilution of Precision (HDOP) in Navigation Theory**
    - **[Location Error S.D.] = [HDOP] X [Raw Time Measurement Error S.D.] X [Speed of Light]**
- **Time Reference**
  - **Accuracy of Local Clock in Measurement System Affects Accuracy**
  - **This Error Component Effectively Canceled Out in TDOA Systems**
- **Site Location**
  - **Site Locations Must be Known to High Accuracy (e.g., 3 meters)**
  - **Possible Using Modern Survey Techniques**
- **System Calibration**
  - **Time of Transmit/Receive Errors due to Local Clock Errors, Cable Runs, etc.**
  - **Means of Measuring and Correcting for these Errors to a High Degree of Accuracy Must be Employed**
    - **Corrections at Initial System Setup**
    - **Monitoring of Errors Over Time**

Location System Error Budget Calculation

- **Assumptions**
  - ALL Error Sources Behave Like Noise (Simplistic/Optimistic)
  - HDOP = 1.0 (Optimistic)
- **Time Measurement Errors Converted to Range Errors**
  - RF Signals Propagate at the Speed of Light (~300,000,000 meters/second)
  - Therefore, a 3.3 nano-second Time Error Translates to an Equivalent Range Error of 1 meter
- **Error Sources Combined in Root Mean Square Fashion**
  - Given e_1, e_2, and e_3
  - $E = \mathrm{sqrt}[e_1^2 + e_2^2 + e_3^2]$
  - Error Sources Characterized in terms of Standard Deviation

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Location Estimation Error Budget

- **Total Error Standard Deviation from ALL Sources Required to Support X m at Y% Accuracy:**
  - **125 meter Total Error: X = 125 meter at Y = 67%**
  - **7.5 meter Total Error: X = 12.2 meters (40 feet) at Y = 90%**
- **Error Source Magnitude Examples**
  - **Site Location: 3 meters**
  - **System Calibration: 15 meters**
  - **Noise: 75 meters**
  - **Multipath: 90 meters**
  - **All Others: 25 meters**
  - **Total of All Error Sources: 121 meters = sqrt($3^2 + 15^2 + 75^2 + 90^2 + 25^2$)**
- **The 125 m at 67% Goal is Achievable**
- **The 12.2 m at 90% Goal is Not Achievable**
  - **Note that this Performance is Unobtainable even if all Error Source Magnitudes are Reduced by an Order of Magnitude**
  - **This level of performance is not achievable by GPS**
    - **Suburban Environment: 30 meters at 90%**
    - **Urban Environment: 55 meters at 90%**

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Other Location Systems

Company	Technology	Type
Accucom	AOA and Signal Strength	Infrastructure Overlay
Associated Group	TDOA	Infrastructure Overlay
KSI	AOA	Infrastructure Overlay
US Wireless	"Channel Signature" to Location Mapping	Infrastructure Add-On
Tendler	GPS	Subscriber Based

- Each System Will Have a Multiple Item Error Budget
  - Some Common Items with TDOA (e.g., Noise, Site Location, Distortion, etc.)
  - Some Different Items from TDOA (e.g., Phase Calibration, Training Errors, etc.)

* **Accountability for Performance Claims can be Encouraged by Requesting Error Budgets from Companies**